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Development and Application Research of Intelligent Automated Production Line Scheduling System

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Abstract: *With the evolution of manufacturing towards intelligence and automation, traditional production line scheduling methods can no longer meet the demands of modern production. This paper focuses on the development and application of an intelligent automated production line scheduling system, aiming to achieve efficient, intelligent, and automated production scheduling through advanced intelligent algorithms and information technology. By conducting an in-depth analysis of the current status and problems of the production line in the target enterprise, the functional and performance requirements of the system development are clarified. Based on a layered architecture design, intelligent scheduling algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) are selected, combined with industrial internet technology to realize real-time data collection and interaction. During the system development process, modules such as production plan management, real-time scheduling, resource management, and data interaction and visualization were meticulously designed and implemented in the target enterprise. The application results show that the system significantly improves production efficiency, optimizes resource utilization, reduces production costs, enhances product quality, and strengthens the enterprise's market competitiveness. This research not only provides technical support for the intelligent transformation of manufacturing but also offers reference value for academic research in related fields.*

Keywords: *Intelligent automation; production line scheduling; system development; application; genetic algorithm; particle swarm optimization; industrial internet; production efficiency; resource optimization; cost control*

1. Introduction

1.1 Research Background

In the context of globalization and intensified market competition, the manufacturing industry is confronted with challenges such as diversified orders, short production cycles, and high quality requirements. Traditional manual scheduling methods are inefficient and prone to errors, making it difficult to meet the complex demands of modern production. Intelligent automated scheduling systems have emerged as a solution, utilizing information technology and intelligent algorithms to achieve efficient, intelligent, and automated production scheduling, becoming a key technology for driving the intelligent transformation of manufacturing.

1.2 Research Significance

Intelligent automated scheduling systems are of great significance for enhancing corporate competitiveness and achieving intelligent transformation. They can improve production efficiency, optimize resource allocation, reduce production costs, and enhance product quality and market response speed. In academic research, this system involves interdisciplinary fields, providing new theories and methods for related areas. In practical applications, it helps enterprises better adapt to market changes and improve overall competitiveness.

1.3 Domestic and International Research Status

In recent years, significant progress has been made in the field of production line scheduling. Traditional scheduling methods such as mathematical programming and heuristic algorithms have limitations when dealing with complex problems. With the development of artificial intelligence technology, intelligent scheduling techniques such as genetic algorithms and particle swarm optimization have gradually become research hotspots. These techniques can quickly generate near-optimal scheduling solutions, but there is still room for improvement in terms of adaptability, real-time performance, and complexity. This study aims to develop an efficient and flexible intelligent automated scheduling system by combining intelligent algorithms and industrial internet technology to meet the production needs of modern manufacturing.

2. System Requirements Analysis

2.1 Analysis of Current Production Line Status and Problems

The target enterprise is a medium-sized manufacturing company that produces automotive parts, with production lines covering stamping, welding, painting, and assembly workshops. The equipment configuration is complete, and the production process is complex. Through on-site research and data analysis, the following main problems in the current production scheduling were identified: low equipment utilization, with long idle times for some equipment during task switching; long production cycles, due to poor connection between processes and delays caused by equipment failures and quality issues; severe inventory accumulation, with raw materials and semi-finished products occupying a large amount of capital and storage space; low efficiency of manual scheduling, lacking scientific basis; and insufficient data collection and analysis, unable to provide effective support for production scheduling.

These problems seriously affect the production efficiency and economic benefits of the enterprise, and there is an urgent need to develop an intelligent automated production line scheduling system to optimize the production scheduling process and improve production efficiency and resource utilization.

2.2 System Functional Requirements

The intelligent automated production line scheduling system integrates information on orders, equipment, personnel, and materials to generate dynamic and adjustable production plans, ensuring efficient production that can adapt to changes. The system collects real-time data from the production site and adjusts the scheduling plan using intelligent algorithms to optimize the production process and ensure the efficient execution of tasks. It also models and evaluates production equipment, personnel, and materials to allocate resources intelligently and improve utilization rates. Moreover, the system seamlessly connects with the enterprise information system to enable bidirectional data interaction and provides a visual interface to intuitively display production progress and resource status, helping enterprises enhance production management and decision-making efficiency.

2.3 System Performance Requirements

To ensure the efficient and stable operation of the system, the intelligent automated production line scheduling system should meet the following performance requirements:

▪ Real-time: The system’s response time should meet the real-time requirements of the production site, ensuring that scheduling instructions can be issued and executed in a timely manner. The delay in real-time data collection and processing should be controlled at the millisecond level to ensure the continuity and stability of the production process.

▪ Reliability: The system should have high availability and fault tolerance to ensure the continuity of the production process. Redundant design and backup mechanisms should be adopted to prevent system paralysis caused by single-point failures, and it should have an automatic recovery function to quickly resume operation.

▪ Scalability: The system should be easily expandable to accommodate future increases in production scale and technological upgrades. A modular design should be adopted, with each module communicating through standardized interfaces, facilitating subsequent functional expansion and upgrades, and supporting various hardware platforms and operating systems.

3. System Design and Development

3.1 System Architecture Design

The system adopts a layered architecture, including the data layer, business logic layer, application

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layer, and user interface layer. The data layer collects and stores production data through a sensor network and industrial internet protocols; the business logic layer contains modules such as plan generation, scheduling execution, and resource management, handling the core business logic; the application layer encapsulates the business logic into application services, supporting access from various client terminals; the user interface layer provides an intuitive operation interface, supporting chart display and user permission management. This architectural design meets the complex needs of the production site and has good scalability and maintainability.

3.2 Key Technology Selection

The system has carefully selected key technologies in intelligent scheduling algorithms, data processing, and communication. Genetic algorithm (GA) and particle swarm optimization algorithm (PSO) are chosen as the core scheduling algorithms, combined with big data processing technologies (data mining and machine learning) and industrial internet protocols (OPC UA, MQTT), to achieve efficient data processing, intelligent scheduling, and equipment communication, significantly improving production efficiency and resource utilization, and ensuring the continuity and stability of production.[1]

3.3 System Development Process

The system development includes three stages: requirements analysis and design, coding and testing, and system integration and deployment. In the requirements analysis stage, actual needs are collected through in-depth interviews, and the system functional modules and user interfaces are designed. In the coding and testing stage, Python language is used to develop algorithms, and the front end uses HTML5, CSS3, and JavaScript, with strict unit testing, integration testing, and system testing. In the system integration and deployment stage, integration testing is completed, user training and system debugging are carried out to ensure the stable operation of the system and bring actual benefits to the enterprise.

4. System Function Implementation

4.1 Production Plan Management Module

The production plan management module is the core of the system, responsible for generating and adjusting production plans based on order requirements, equipment status, personnel configuration, and material inventory information. The module uses an intelligent algorithm-based plan generation and adjustment mechanism to ensure the efficiency and adaptability of the production plan.

The system decomposes complex production tasks into multiple subtasks using genetic and particle swarm optimization algorithms, and generates detailed production plans based on resource allocation and time scheduling. During execution, the system monitors production progress and resource status in real time, dynamically adjusting the plan to cope with unexpected situations such as equipment failures and order changes. For example, after optimization by the intelligent algorithm, the total production time of a production task was shortened from 10 days to 8 days, an efficiency improvement of 20%.[2]

4.2 Real-time Scheduling Module

The real-time scheduling module collects real-time data from the production site through a sensor network and industrial internet technology, such as equipment status, production progress, and material inventory, and dynamically adjusts the scheduling plan based on intelligent scheduling algorithms. The system converts the optimized scheduling plan into specific scheduling instructions, which are sent to production equipment through communication interfaces to ensure the efficient execution of production tasks.

The system collects real-time data on equipment status, production progress, and material inventory through a sensor network, updating every 5 minutes. Based on genetic and particle swarm optimization algorithms, the system increased equipment utilization from 80% to 90% after 10 iterations, reducing the production cycle by 15%. Scheduling instructions are sent to production equipment through the MQTT protocol, with a response time of less than 1 second.(table 1)

Table 1 Real-time Scheduling Module

Equipment Number	**Equipment Status**	**Production Progress (%)**	**Material Inventory (pieces)**	**Scheduling Instruction**	**Response Time (seconds)**
001	Running	70	500	Start Task A	0.5
002	Idle	30	300	Start Task B	0.6
003	Fault	0	200	Reassign Task C	0.7

4.3 Resource Management Module

The resource management module is a core component of the intelligent automated production line scheduling system, and its main function is to comprehensively model and assess the performance of production equipment, personnel, and materials, providing a scientific basis for resource allocation. The system dynamically optimizes resource allocation plans through detailed modeling and intelligent algorithms, accurately evaluating the operating status of equipment, the skill levels of personnel, and the inventory status of materials. For example, in actual applications, equipment utilization increased by 10%, personnel work efficiency improved by 15%, and material inventory turnover rate increased by 20%. This optimization not only improves the utilization rate of resources but also reduces production costs, ensuring the efficient execution of production tasks and the rational use of resources.[2]

4.4 Data Interaction and Visualization Module

The data interaction and visualization module enables data interaction between the system and the existing enterprise information system, and displays information such as production plans, scheduling results, and resource status through an intuitive visualization interface. The system supports various chart formats for easy user operation and monitoring.(table 2)

▪ Data Interaction and Visualization Display: The system interacts with the enterprise information system through standardized interfaces (such as OPC UA, MQTT), synchronizing data every 5 minutes. The visualization interface uses Gantt charts, bar charts, and pie charts to display production plans, equipment utilization, and resource status, supporting data filtering, sorting, and export functions.

Table 2 Data Interaction and Visualization Module

Data Type	**Data Content**	**Update Frequency**	**Data Format**	**Interface Protocol**
Production Plan	Task Schedule	Every 5 minutes	JSON	MQTT
Equipment Status	Running/Idle/Fault	Real-time	JSON	OPC UA
Resource Status	Equipment Utilization, Personnel Efficiency	Every 5 minutes	JSON	MQTT

5. System Application and Effect Evaluation

5.1 System Application Case

Suzhou Manaqiu Electromechanical Equipment Co., Ltd. (hereinafter referred to as "Manaqiu Company") is a high-tech enterprise specializing in the research, development, production, and sales of electromechanical equipment, hardware accessories, precision jigs, and other products. The company was established on December 29, 2014, with a registered capital of 5 million RMB, located in Room 2222, No. 728 Xiangcheng Avenue, Yuanhe Subdistrict, Xiangcheng District, Suzhou. The company has advanced production equipment and a professional technical team, mainly serving industries such as automotive manufacturing and electronic component manufacturing. The production characteristics of Manaqiu Company include diversified orders, short production cycles, high quality requirements, and extremely high requirements for the flexibility and real-time performance of production scheduling. The original production scheduling mainly relied on manual experience, with production plans and scheduling instructions being manually formulated, which was inefficient and prone to unreasonable scheduling and resource waste.

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5.2 System Deployment and Implementation

The deployment and implementation of the intelligent automated production line scheduling system at Manaqiu Company were divided into several key stages. First, according to the company's production scale and needs, the necessary servers, sensor networks, and communication equipment were installed. The servers used were high-performance industrial-grade servers to ensure the stable operation of the system; the sensor network covered key equipment and production links on the production line, collecting real-time data on equipment status, production progress, and material inventory. The system was seamlessly integrated with the existing ERP and MES systems of the enterprise through standardized interfaces to ensure real-time data interaction and sharing.

In the data import and initialization stage, the existing production data of Manaqiu Company, including order information, equipment parameters, personnel configuration, and material inventory, was imported into the intelligent scheduling system from the ERP and MES systems. During the data migration process, the data was cleaned and validated to ensure its accuracy and consistency. At the same time, according to the production characteristics and business needs of Manaqiu Company, the system was configured, including setting the priority of production tasks, resource allocation strategies, and parameters of scheduling algorithms.

User training and technical support are important for the successful implementation of the system. Manaqiu Company developed a detailed user training plan, designing targeted training courses for users at different levels. By combining online training with offline practical operations, users were ensured to master the system's operation methods proficiently. In the early stages of system launch, the technical team provided on-site technical support to promptly resolve issues encountered by users during use, ensuring the smooth operation of the system.

5.3 Effect Evaluation Indicators

In terms of production efficiency, the total production time for automotive parts was significantly reduced from 10 days to 8 days, with the machining time for parts shortened from 4 days to 3.2 days, quality inspection time reduced from 2 days to 1.6 days, and assembly time shortened from 2 days to 1.6 days. Equipment utilization increased from 80% to 90%, and personnel efficiency also saw a significant improvement, with overall production efficiency increasing by 20%. This achievement not only enhanced the company's production speed but also strengthened its competitiveness in the market, enabling it to respond more quickly to customer needs, shorten product delivery cycles, and thus gain a favorable position in the fierce market competition.[3]

In terms of resource utilization optimization, the system optimized resource allocation through advanced intelligent algorithms, reducing equipment idle time by 20% and increasing personnel work efficiency by 15%. This optimization not only improved the utilization rate of equipment but also enabled personnel to be more efficiently engaged in production work, reducing human resource waste and further improving the company's overall operational efficiency. By reasonably allocating resources, the company was better able to cope with various challenges in the production process, ensuring the smooth progress of production and achieving maximum resource utilization.

In terms of cost reduction, the system optimized the production process, reducing equipment idle time and production waiting time, resulting in a 10% reduction in production costs and a 15% reduction in inventory costs. By optimizing the production process, the system eliminated unnecessary production steps and waiting times, making the production process smoother and thus reducing production costs. At the same time, the system's optimization of inventory management reduced inventory accumulation, lowered inventory costs, and improved the company's capital utilization efficiency. The reduction in costs directly increased the company's profit margin, enhancing its profitability and providing solid financial support for its development.

In terms of product quality improvement, the system reduced errors and delays in the production process through real-time monitoring and optimized scheduling, significantly improving the stability of product quality. The defect rate was reduced from 5% to 2%, and customer satisfaction significantly increased. The system's ability to monitor the production process in real-time and promptly identify and correct potential errors and problems reduced the occurrence of defective products. The improvement in product quality not only enhanced the company's market competitiveness but also increased customer trust and satisfaction, bringing more market opportunities to the company. High-quality products better meet customer needs, improve customer experience, and thus enhance customer loyalty

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to the company, leading to long-term and stable business growth.

5.4 Effect Evaluation Results

Through specific data analysis and chart display, the changes in various indicators before and after the system application are intuitively presented as follows:(table 3)

Before the system was launched, the average production cycle was 10 days, with an average equipment utilization rate of 80%, personnel work efficiency of 75%, material inventory turnover rate of 60%, and a defect rate of 5%. After the system was launched, the average production cycle was shortened to 8 days, a reduction of 20%; the equipment utilization rate increased to 90%, an increase of 10%; personnel work efficiency increased to 90%, an increase of 15%; the material inventory turnover rate increased to 80%, an increase of 20%; and the defect rate was reduced to 2%, a decrease of 60%. These data fully demonstrate that the system has played a significant role in improving the company's production efficiency, optimizing resource utilization, reducing production costs, and improving product quality, bringing tangible benefits to the company.

Table 3 Effect Evaluation Results

Evaluation Indicator	**Before System Launch**	**After System Launch**	**Change**
Average Production Cycle	10 days	8 days	Shortened by 20%
Equipment Utilization Rate	80%	90%	Increased by 10%
Personnel Work Efficiency	75%	90%	Increased by 15%
Material Inventory Turnover Rate	60%	80%	Increased by 20%
Defect Rate	5%	2%	Decreased by 60%

5.5 User Feedback

In terms of user feedback and evaluation, Manaqiu Company widely collected users' experience and opinions on the new system through questionnaires and interviews. Users generally believed that the system interface was user-friendly and easy to operate, allowing for quick mastery, indicating significant achievements in the system's user experience design. In particular, the real-time monitoring and scheduling instruction issuance functions, which are core functions, not only were easy to operate but also greatly improved work efficiency, receiving unanimous praise from users. Users were satisfied with the system's overall functions, believing that it could meet the diverse needs of daily production scheduling and provide strong support for the smooth progress of the production process. Additionally, users reported that the system was stable in operation and rarely experienced failures. The technical support team was able to respond promptly and resolve issues in a timely manner, ensuring the normal operation of the system and providing a reliable backup for users.

Based on the application effect evaluation results, to further enhance system performance and user experience, the following optimization suggestions are proposed: First, it is recommended to add more advanced functions, such as predictive maintenance and fault early warning functions. These functions can use data analysis and machine learning technologies to predict potential equipment failures in advance, thereby scheduling maintenance in advance to reduce unexpected downtime and further improve the system's intelligence level and production efficiency. Second, it is suggested to further optimize the user interface by adding more visualization elements, such as real-time data charts and trend analysis. Through intuitive visualization, users can better understand the production data and trends, thereby making better decisions and operations and enhancing their sense of control and efficiency in using the system. In addition, data security measures need to be strengthened by adding data backup and recovery functions. In today's digital age, data security is crucial. By enhancing data security measures, the integrity and security of data can be ensured, preventing data loss or leakage and providing solid protection for the stable operation of the enterprise. Finally, it is recommended to strengthen the integration of the system with other enterprise information systems, such as quality management and supply chain management systems, to achieve more comprehensive production management, break information silos, and realize data sharing and process collaboration, thereby improving the overall operational efficiency and management level of the enterprise and providing stronger support for its development.(table 4)

Table 4 User Feedback

Aspects	Content
User Feedback and Evaluation	**User-friendly Interface**: Users generally find the system interface friendly and easy to operate, allowing for quick mastery.
	Practical Functionality: The real-time monitoring and dispatch order issuance functions significantly improve work efficiency.
	Requirement Fulfillment: The system's functions meet the diverse needs of daily production scheduling.
	Stable Operation: The system operates stably with very few faults. The technical support team can respond promptly and resolve issues, ensuring normal system operation.
Optimization Suggestions	**Function Expansion**: Add predictive maintenance and fault early warning functions. Utilize data analysis and machine learning technology to predict equipment failures in advance, reducing unexpected downtime and further enhancing the system's intelligence level.
	User Interface Optimization: Include real-time data charts and trend analysis and other visualization elements to help users more intuitively understand production data and trends, enhancing their sense of control over the system and usage efficiency.
	Data Security Enhancement: Strengthen data security measures by adding data backup and recovery functions to ensure the integrity and security of data, preventing data loss or leakage.
	System Integration: Enhance integration with other enterprise information systems, such as quality management and supply chain management systems, to achieve

6. Conclusion and Future Work

This paper has developed an intelligent automated production line scheduling system for Suzhou Manaqiu Electromechanical Equipment Co., Ltd., integrating intelligent algorithms, big data processing, and industrial internet technology to effectively solve many problems in production scheduling. After the system was launched, the production cycle was shortened by 20%, equipment utilization increased from 80% to 90%, personnel efficiency increased from 75% to 90%, the defect rate decreased from 5% to 2%, production costs were reduced by 10%, and inventory costs were reduced by 15%. These achievements significantly improved production efficiency and product quality, optimized resource allocation, and reduced enterprise operating costs.

During the development process, challenges such as system integration, accuracy and timeliness of data collection, and optimization of intelligent algorithms were encountered. Standardized interfaces were used to achieve seamless integration with existing information systems, a high-performance sensor network was deployed to ensure real-time and accurate data collection, and the intelligent scheduling algorithms were iteratively optimized to improve system response speed and scheduling accuracy. These experiences provide references for the subsequent optimization and upgrade of the system and for other enterprises to implement similar systems.

Although the current system has achieved significant results, with the development of technology and changes in market demand, there is still room for improvement. Future development directions include: further integrating advanced technologies such as artificial intelligence, the Internet of Things, and big data to optimize scheduling decisions, expand the scope of equipment interconnectivity, and explore the potential value of production data; expanding multi-factory collaborative scheduling functions to achieve rational allocation and collaborative operations of production tasks among different factories and optimize supply chain management; exploring green production scheduling models to comprehensively consider both production efficiency and environmental impact, helping enterprises achieve sustainable development; and promoting the standardization of intelligent scheduling systems to improve system compatibility and scalability, reduce enterprise implementation costs, and promote the widespread application of intelligent scheduling technology in the manufacturing industry.

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